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ORIGINAL ARTICLE

Management of mass casualty burn disasters

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Introduction

Mass casualty burn disasters are potentially challenging, in part because the majority of health care providers are inexperienced in the care of thermally injured patients and in part because of the multi-system response elicited by the thermal injury. Management expertise is generally concentrated in burn centres, whereas in a true mass casualty event, personnel at other hospitals may need to provide burn care for extended periods of time. In addition, burn care is time-, manpower- and resource-intensive. Finally, the risk of terrorist attacks which can result in large numbers of burn casualties persists; inhalation injury and burns were the leading causes of injury among survivors of the 11 September 2001 attacks in New York City (1) and the 12 October 2002 bombing in Bali (2). This reflects the observation that 'terrorists prefer simple, easily accessible weapons, such as fertilizer, cellular telephones, box cutters, and jet fuel, to complex and hard-to-deploy weapons such as biologic and chemical agents' (3). The purpose of this article is to review recent experience with burn disasters worldwide, to recommend a set of general principles for burn disaster management, and to describe the current status of burn disaster planning at the national level in the USA.

Lessons learned

Critical analysis and careful documentation have, over the past several decades, improved our understanding of how best to prepare for and respond to mass casualty burn disasters. For example, it is widely recognized that the scientific approach employed in the treatment of the survivors of the Cocoanut Grove fire of 1942 formed the foundation for many of the subsequent advances in burn care. It was fortuitous that the bombing of Pearl Harbor in 1941 –approximately half of the casualties from which had burns (4) – had generated an awareness of the need for an increase in burn research. Thus, several research projects were ongoing at the Massachusetts General Hospital and the Boston City Hospital by the time of the Cocoanut Grove fire (5). Research is possible even in a mass casualty disaster, and may be essential if we are to learn from these incidents.

Table I provides a summary of several recent case reports on burn mass casualty disasters throughout the world. Salient findings from these reports are summarized below and in Table II. Although each burn disaster is in some respects unique, the problems encountered in each and the identification of effective interventions have contributed to our understanding of how to handle such events and have led to development of the current US perspective on the optimal response to such incidents.

The value of candid after-action review was demonstrated by Ishida et al., reporting on the 1970 Osaka natural gas line explosion in an urban area (6). Several weaknesses were identified in their system, including lack of central command and control, resulting in lack of communication among emergency medical services (EMS), fire and police. There was no field triage, which caused hospital physician time to be wasted. There was a need to control the media. These authors reported that following the Osaka disaster a system was put into place that corrected these problems (6). Whether these interventions enabled Osaka to respond more

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Table I. Selected recent burn mass casualty disasters.

Date	References	Location	Cause	Number of injured survivors*	Number of on-scene dead†
1970	(6)	Osaka, Japan	Natural gas pipeline	428	79
1976	(67)	Nakivubo, Kampala, Uganda	Gasoline tanker truck	71	11
1977	(68,69)	Southgate, Kentucky, USA	Supper club fire ('Beverly Hills')	5	160
1978	(7)	Los Alfaques, Spain	Liquid propylene gas	140	102
1980	(8)	Las Vegas, Nevada, USA	Hotel fire ('MGM Grand')	726	84
1981	(70,71)	Dublin, Ireland	Nightclub fire ('Stardust')	44	48
1981	(72)	Bangalore, India	Circus fire	169	92
1982	(73)	Cardowan, UK	Coal mine explosion	40	0
1984	(9)	San Juanico, Mexico	Liquid propane gas	7230	300
1985	(10)	Bradford City, UK	Football stadium fire	256	52
1985	(74)	Manchester, UK	Aeroplane fire	79	52
1988	(11)	Piper Alpha platform, North Sea, UK	Oil rig fire	25	167
1988	(41)	Ramstein, Germany	Aeroplane crash	400	45
1989	(13)	Bashkiria, Russia	Natural gas pipeline	800	400
1990	(75)	Väderöarna, Sweden	Fire on ferry boat (*Scandinavian Star*)	30	158
1994	(14,76)	Pope Air Force Base, North Carolina, USA	Aeroplane crash	119	11
1998	(16)	Gothenburg, Sweden	Discotheque fire	213	60
2001	(17)	Volendam, The Netherlands	Café fire	245	4
2001	(1,21,77)	New York City, USA	Aeroplane attacks (World Trade Center)	790	2713‡
2002	(2,23,24)	Bali, Indonesia	Nightclub bombings	155 (78)	202‡ (79)
2003	(25)	West Warwick, Rhode Island, USA	Nightclub fire ('Station')	215	96

*Where available, this number refers to casualties arriving alive at hospitals or other medical treatment facilities, and receiving either inpatient or outpatient care; includes patients with burns, inhalation injury, and other injuries. †Where available, this number refers to casualties dead at the scene. ‡Final estimate of all deaths caused by the event.

effectively during the massive earthquake of 1995 in nearby Kobe is difficult to determine.

Acting as a representative of the Swedish Committee for Disaster Medicine (KAMEDO), Arturson analysed the 1978 liquid petroleum gas tanker truck explosion in Los Alfaques, Spain (7). Based on their location relative to the blocked highway, one group of 82 patients was bussed south, without medical care for many hours, for 150 km to a hospital in Valencia; while 58 patients were taken north, with en route medical care, to Barcelona. As a consequence, the survival rate of the first group 4 days post burn was 45%, vs 93% for the second group – indicating the importance of controlling both the routes and types of conveyances used for evacuation.

The value of disaster planning and training was demonstrated by Buerk et al., reporting on the 1980 MGM Grand Hotel fire in Las Vegas, Nevada; 3000 persons were triaged within 3.5 hours of the fire (8). Of those patients only 726 were referred to 4 local hospitals; 1700 minimally injured or displaced persons were transported via school buses to a 'refuge center' located well away from the disaster area, helping to maintain order at the scene. The single on-site triage point was overwhelmed, necessitating the creation of two additional triage stations at various points around the hotel. To coordinate efforts at these three sites, a central command post was established.

Arturson also reported on the San Juanico explosion of 1984, the worst liquid petroleum gas disaster in history (9). An idea of the magnitude of this disaster can be gained from the fact that 625 patients were hospitalized with severe burns – 175 at each of 2 hospitals; 140 of the burn patients died within the first 5 days. The first few hours after this explosion were characterized by chaos; there was no organized evacuation process, and all roads leading out of the town were clogged by refugees, preventing the rescue of patients. Response to this disaster was aided by the activation of the Mexican Army's earthquake disaster plan (9).

Sharpe and Foo reported on the 1985 football match in Bradford City, UK (10). Most of the injured were evacuated by private car or bus to local hospitals, often arriving without any warning. Triage at the hospital was performed by a consultant plastic surgeon. These authors commented that in order to prevent the burn centre from becoming overloaded, patients with non-survivable injuries as well as those with minor injuries should be treated in a location other than the burn centre. Most burn patients can be managed as outpatients, and thus an outpatient clinic is essential for effective burn disaster response (10).

The importance of long-term psychological and occupational support for burn disaster survivors was emphasized by Hull et al., who recently reported 10-

Table II. Lessons learned from burn mass casualty disasters.

Disaster	Disaster plan	Command, control, communication	Triage	Transport	Treatment strategies	Personnel management	Supplies and equipment	Transfer	International response	Rehabilitation and long-term follow-up
Osaka		*	*							
Los Alfaques		*	*	*						
Las Vegas	*	*	*	*	*					
San Juanico	*	*	*	*						
Bradford City		*	*	*	*					
Piper Alpha										*
Bashkiria									*	
Pope AFB					*	*	*	*		
Gothenberg		*	*	*	*					*
Volendam			*					*	*	*
World Trade Center		*	*			*		*		
Bali		*				*		*	*	
Station Nightclub		*		*		*				

*Indicates that the available literature on the event comments on this area, describing it as either a strength or as a weakness of the disaster response.

year follow-up data on 33 of 59 survivors of the 1988 Piper Alpha oil rig fire (11). Twenty-two percent of the 33 subjects met criteria for post-traumatic stress disorder (PTSD) at the time of the study, and 73% retrospectively met criteria for PTSD during the first 3 months after the disaster. The majority (78%) reported difficulties finding work (11).

The Bashkirian train-gas pipeline disaster of 1989 in the former Soviet Union provided an example of effective non-wartime international cooperation in the management of a burn mass casualty disaster (12). Four days after the disaster, the USSR government asked the US government for assistance; 45 hours later, a US Army Burn Center team of 17 personnel with 7000 kg of equipment and supplies arrived in Ufa, Russia. The team included three general surgeons experienced in burn care, three registered nurses, three licensed vocational nurses, three respiratory therapists, a microbiologist and a laboratory technician. These personnel were augmented 1 week later by an anaesthesiologist, an occupational therapist, a physical therapist and an operating-room technician. Care provided by this team included excision and grafting of burn wounds, microbiological surveillance and rehabilitation. Techniques such as topical treatment of burn wounds with mafenide acetate and selection of antibiotics based on sensitivity testing were necessary, as by that time the essentially untreated wounds of the patients were heavily colonized, and in some cases infected (13).

Phillips et al. reported on the 1994 Pope Air Force Base (AFB) aircraft crash from an anaesthesiology perspective (14). Those authors noted critical shortages of laryngoscopes, endotracheal tubes, anaesthesia drugs and similar supplies, noting that these should be pre-positioned in the emergency department. A single pharmacy representative was useful in providing drugs. Patients with minimal injuries were directed to go to clinics. Ventilators were scarce; thus, not all patients were intubated immediately, and 'airway rounds' were conducted periodically to re-evaluate both intubated and at-risk patients. Two hospital wards became intensive care units (ICUs), and non-ICU physicians were recruited from field units to manage these patients. The authors concluded that it was challenging to remain organized and focused; and that it was important not to move too quickly from one patient to another, but to concentrate on completing critical tasks on a single patient before moving on (14).

The disaster at Pope AFB also provided a rare peacetime example of involvement of US Army Burn Flight Teams in initial care, triage and transport of burn patients during a disaster. By 7 hours after the crash, 3 such teams had arrived on site; they stabilized 20 critically ill, severely burned patients and evacuated them to the Army Burn Center in Texas, where they arrived 21 hours after injury.

Thirteen of these patients required continuous in-flight mechanical ventilation. An additional 23 patients, including 3 critically ill patients, were subsequently transported to the US Army Burn Center under Burn Flight Team supervision. All of the patients transported to the Army Burn Center survived (15).

Cassuto and Tarnow described problems encountered in managing casualties from the 1998 Gothenberg discotheque fire (16). There was lack of crowd control at the scene; bystanders interfered with first aid efforts in an attempt to get help for their own next of kin, and one rescuer was attacked by bystanders. On-scene triage was made difficult by the absence of an experienced disaster physician. A trailer with disaster equipment and supplies, which were quickly exhausted at the scene, should have been deployed earlier. They also reported that pain control at the scene was effectively managed with small doses of i.v. ketamine and that buses could be used to transport patients with minor injuries. The authors make the important point that any disaster plan should include provision for rehabilitation and for helping the survivors with the grieving process (16).

Kuijper reported on the largest burn disaster in Dutch history, which occurred in January 2001 in a café in Volendam (17). One hundred and eighty-two burn patients were admitted to 21 hospitals and 94 of those patients required mechanical ventilation after the first 24 hours post burn. Prior to this disaster, the Netherlands had created burn triage teams (B-Teams). In the Volendam disaster, once the B-team was activated, it travelled to various regional hospitals and determined which patients needed to be transferred. Because of the large number of burn patients, some were transported to burn centres in Belgium and Germany – indicating the importance of international cooperation in responding to major burn disasters (17).

Events at the scene of the terrorist attacks on the World Trade Center (WTC) and the responses of nearby hospitals have been described (18–20). In addition, Yurt and colleagues reviewed their experience with casualties from that disaster who were treated at the New York-Presbyterian burn centre (21). A total of 39 surviving casualties sustained significant burn injuries in that attack; however, only 28% of these patients were initially triaged to burn centres. This becomes more understandable when taken in context. As those authors point out, 'triage was only possible in the earliest minutes prior to the collapse of the WTC and … after that, escape and survival became the mission of the survivors'. Subsequently, retriage resulted in admission of a total of 66% of the burn patients to regional burn centres, and of 21 patients to the New York-Presbyterian burn centre. The major manpower needs were in the area of nursing, and the burn centre was assisted by National Disaster Medical System Burn Specialty Team nurses and a surgeon. A day-long orientation programme was provided for the nurses with special emphasis placed on the computerized medical record. Considering that had the WTC towers not collapsed the number of injured might have been much higher, the authors concluded that improved methods of transferring burn patients regionally and nationally should be identified (21).

Several authors have reported on the Bali bombing of 2002, Australia's largest offshore disaster requiring urgent evacuation. Southwick et al., who were present in Bali at the time of the attack, described immediate care under austere conditions. Remarkably, a number of non-medical volunteers were assigned and successfully performed basic patient-monitoring tasks, such as measuring urine outputs and checking i.v. infusion rates (22). Hampson et al. led the Royal Australian Air Force evacuation of 66 casualties from Bali to the Royal Darwin Hospital (1765 km) using five C130 aircraft. An aeromedical staging facility was set up in a hangar at the airfield in Bali; satellite communications were essential in coordinating this effort (23). A number of civilian air ambulance companies also participated; lack of coordination among these organizations and the military was recognized as an area for improvement (24). The Royal Darwin Hospital was the primary receiving hospital for these casualties in Australia, processing 61. The first of these patients arrived roughly 24 hours after injury. The challenges inherent in a prolonged transfer such as this are exemplified by the fact that 12 of these patients required intubation upon arrival in Australia, many in the presence of progressive facial and airway oedema. From this hospital, patients were transported to burn centres throughout the country. The stress imposed on health care personnel unaccustomed to caring for burn patients necessitated the almost immediate institution of critical incident stress debriefing, which was continued for 4 weeks (2).

Harrington and colleagues described the Station Nightclub fire of February 2003 in Rhode Island, the fourth deadliest nightclub fire in US history (25). A triage station was set up across the street soon after the fire, but medical command and control was lacking and individual ambulance crews decided where to transport patients. There was limited communication between the scene and the burn centre, and among regional hospitals. Thus, there was a lack of real-time situational awareness of patient movement and hospital capabilities throughout the region. As a result, a statewide trauma system is now being created with the support of the American College of Surgeons Committee on Trauma. This system will involve a central command structure and a communications system.

During previous mass casualty incidents, those authors had experience with placing the lead surgeon in the operating room, in the incident command centre, and finally in the emergency room. The latter siting worked well for casualty management during the response to the Station Nightclub fire. Moreover, use of standardized Clinical Practice Guidelines enabled those authors to employ non-burn surgeons and others to provide burn care (25).

Management principles

Based on these and similar experiences, one can elucidate a set of principles for the management of burn disasters. These principles are similar to those applicable to other mass casualty events, modified as needed for the unique features of thermal injury and any unique features of a given disaster. Most of the reports summarized above emphasize that the disaster scene was characterized by chaos. One can anticipate, therefore, that a fire disaster will be inherently chaotic (10). However, the events and actions that occur at a disaster are not random, and certain behaviours (such as use of private vehicles for self-evacuation) are predictable. An effective response must include an effort to comprehend, adapt and respond to this chaos – seeking to apply these basic management principles to the situation at hand in order to establish prompt, equitable command and control of casualty care activities.

Disaster plan

First of all, there must be disaster plans in place for the hospital, community, region and nation, which envision how to handle progressively larger numbers of burn casualties. In all but 1 of the 14 burn disasters analysed by Arturson, no disaster plan was in place (26). Conversely, the efficacy of an established, recently exercised plan was demonstrated, for example, in Las Vegas (8). Disaster plans should be individualized to an organization's strengths and limitations. *Resources for Optimal Care of the Injured Patient: 1999*, published by the American College of Surgeons Committee on Trauma, provides an extensive checklist that can serve as an outline for developing a hospital disaster plan (27). One must also be cognizant of how the local disaster plan fits into the national plan. Accordingly, and because the US National Response Plan is relatively complex, we have devoted a separate section, below, to this plan.

Command, control and communication

A community's Incident Command System, with clearly defined roles and responsibilities, must be established well before disaster occurs and must be activated as soon as possible during the disaster response (28). Adequate and redundant means of communication among command and control elements, triage station(s), receiving hospitals and regional burn centres is critical to an effective burn disaster response. The burn centre should be integrated into the regional disaster response system, such that the burn centre director has communications capabilities and is notified early during a fire disaster. Within a region, burn centres should possess and exercise inter-centre communications (29). This is essential for the rational distribution of burn patients to available beds.

Triage

As in other types of mass casualty events, triage is an essential component of burn disaster management: 'for the surgeon facing 30 victims of urban terrorism, the 3–4 badly injured but salvageable patients are the hidden crux of the entire effort' (30). Fortunately, severity of injury can be determined rapidly by considering total extent of burn, age of patient and the presence or absence of inhalation injury or associated severe mechanical trauma (31). What constitutes a non-survivable burn? This can be gauged by considering the lethal area fifty percent, L_A50, for a given age group. For example, in the US this is currently about 80% of the total body surface area for young adults. This means that half of young adults with burns of 80% of the total body surface area can be expected to survive. During a mass casualty scenario, it may be necessary to triage patients in that age group with burns in excess of 80% to the expectant category. Individual burn centres and regional trauma systems may perform similar analyses, in order to permit an evidence-based approach to triage. The presence of inhalation injury, or of severe mechanical trauma, should add 10% to the burn size for this calculation (i.e. reduce the L_A50 by 10%). Patients with burns of 20% or less (10% or less at the extremes of age) can be triaged to the delayed or minimal care category. The majority of burn patients in any scenario typically have small burns (32). Average burn size was higher following outdoor fire disasters than following indoor fire disasters in a series reviewed by Arturson, possibly reflecting difficulty on the part of extensively burned casualties in exiting burning buildings (26). As a rough guide, one can expect that 80% of the patients will have non-life-threatening burns of 20% of the body surface area or less (15). This percentage is similar to non-burn data reported for recent multiple casualty incidents in Israel (33).

Whenever possible, triage should be performed by an experienced burn surgeon (32). Burn size is commonly greatly overestimated by inexperienced providers; in a mass casualty scenario, such overestimation is likely (i) to triage patients with large but survivable burns to the expectant category incorrectly, and (ii) to increase mortality of critically injured patients by inundating overwhelmed medical facilities with non-critical patients (34).

Triage should be performed outside the hospital (33), initially at the scene of the disaster. Three levels of on-scene triage have been described. In Level 1 triage, patients are sorted as acute or non-acute; in Level 2 triage, acute patients are sorted as delayed, immediate, minimal, expectant, or dead; and in Level 3 triage, patients are sorted according to evacuation priority (35). If an experienced burn surgeon is not available to perform on-scene triage (10), patients must be retriaged upon arrival at the hospital, and *before entering* the emergency department. Once triaged, patients with minimal injuries need to be kept out of the emergency department and burn centre. Nevertheless, they will have significant care needs. The use of an outpatient clinic for such minimal care is appropriate.

It is now recognized that triage is an ongoing, dynamic process. Patients need to be re-evaluated every few hours, which may result in a change in triage category (35). Secondary triage, whereby patients are selected for transfer to other hospitals, should likewise be programmed. Failure to perform secondary triage, and to transfer patients to available burn beds elsewhere in a timely fashion, risks degrading the quality of patient care by overwhelming the primary facility (36).

Transport

Relatedly, centralized control of ambulance services, and of patient transport from the scene, enables patients to be distributed appropriately. Several of the burn disasters described above featured the uncoordinated evacuation of patients from the scene by private conveyances, which risks both inundating a receiving hospital and depriving the patients of adequate en route medical care (7). On the other hand, such use of private conveyances may at times be inevitable.

Treatment strategies

The care of individual patients by burn specialists is often labour-intensive. In a burn mass casualty disaster, then, careful thought must be given to how best to manage a large number of patients with limited numbers of experienced personnel. The usual ICU model of one nurse for one patient may not be possible and some have suggested formation of teams focusing on specific functions, such as teams dedicated to airway management, fluid resuscitation, pain management and wound and extremity care (14). However, the safety and efficacy of such an approach to patient care has not been tested. Alternatively, Wachtel and Dimick suggest a plan in which a single caregiver, such as a nurse, accompanies each seriously injured patient throughout the initial phases of care (36), taking maximal responsibility for all critical interventions. Computerized records, which require in-depth orientation for new providers (21), should be discarded in favour of simple bedside paper charts. Rather than providing direct patient care, experienced burn surgeons and nurses may be best utilized in management roles, overseeing the efforts of non-burn ICU personnel. Occupational and physical therapists can be used to perform wound care functions (dressing changes, application of topical antimicrobial burn creams) normally performed by nurses. The use of standardized and simplified Clinical Practice Guidelines – both before the incident and during it – permits burn care personnel to perform critical tasks without continuous physician supervision, and facilitates the integration of non-burn personnel during the crisis (25,26). Finally, non-medical tasks, such as family and media liaison, are best handled in a mass casualty crisis by non-burn personnel (36).

Personnel management

Providers may be tempted to respond directly to the scene of the disaster. Whereas on-scene triage by burn personnel as part of the disaster plan may be appropriate (25), uncoordinated efforts may be counterproductive. Commenting on events in New York City on 11 September 2001, one observer noted: 'Cowboy initiatives begin. Doctors attempt to commandeer transport to go to the site carrying potentially scarce supplies, such as morphine' (37). Such entrepreneurship is of little benefit to patients, and places providers at risk of injury: 'physicians and nurses … scattered in fear when rumors of an adjacent building's imminent collapse circulated' (18). In anticipation of the need for personnel to rest, scheduled work hours and a meal plan should be set up (18). Likewise, psychological debriefing for providers should be initiated as soon as possible. Within a day or two of a mass casualty incident, rather than staffing shortages, a major challenge may be how best to coordinate the activities of the large number of volunteers who typically arrive: 'Volunteers will come!' (36).

Supplies and equipment

The burn centre should maintain and exercise the ability to expand its critical care capacity, for example, by using transport monitors and ventilators to convert acute care wards into ICUs (25,38). Maintaining a list of supplies and equipment needed to support a mass casualty incident, with up-to-date catalogue numbers, prices and contact information, greatly accelerates the ordering process during an emergency. Such lists should be generated ahead of time to cover resuscitative care (the first 72 hours post burn), surgical care, laboratory support and rehabilitation.

Transfer

A mature appreciation on the part of the hospital, region or nation of its ability to care for burn casualties during a disaster is needed and, when appropriate, should motivate the timely transfer of patients to available, qualified facilities. Central to this concept is the understanding that patients with severe thermal injuries should receive their care in nationally recognized burn centres (38–40). In the USA, the voluntary burn centre verification programme, collaboratively directed by the American College of Surgeons Committee on Trauma and the American Burn Association, identifies and verifies burn centres that meet national standards for quality of care. Particularly in Europe, international transfer of burn patients has been essential in the successful management of several disasters (16,17,41).

Within a community or region, short-distance transport of burn patients is commonly accomplished by ambulance personnel who typically do not have extensive burn training. However, the safe long-distance aeromedical evacuation of burn patients necessitates the use of teams which are experienced not only in aviation medicine, but also in burn intensive care. In the USA, this has been accomplished since 1951 by the use of Burn Flight Teams based at the US Army Institute of Surgical Research (USAISR, the US Army Burn Center) (42). These teams consist of a burn surgeon, a critical care registered nurse, a licensed practical nurse, a respiratory therapist and one additional operations sergeant (usually a senior licensed practical nurse). All of these personnel are drawn from the burn intensive care unit and, in addition, complete the US Air Force Critical Care Air Transport (CCAT) course. The Disaster Planning Committee of the International Society for Burn Injuries has adopted this basic disaster burn care team model, the composition of which can be modified as needed for a given disaster (15).

Although aeromedical evacuation exposes potentially unstable burn patients to risk, such risk has been mitigated by the use of these specially trained teams. Thus, during the Vietnam conflict the US Army Burn Flight Teams carried out 103 aeromedical missions to transport 824 patients from a burn holding unit in Japan to the US Army Burn Center in San Antonio, Texas. Only one in-flight death occurred during those transfers of critically ill, severely burned patients (15,43).

With respect to timing, long-range evacuation is best accomplished during a narrow window after haemodynamic stability has been achieved, but before the risk of infection intervenes: ideally between post burn days 1 and 4 (43,44). During 1980–1995, the teams transported 1196 burn patients, including 542 out-of-state transfers and 59 out-of-country transfers over a total cumulative distance of approximately 850 000 miles, without the occurrence of in-flight mortality or major complication. The mean burn size of these patients was 35.9% of the total body surface area, and 52.3% had inhalation injury (45).

The burn flight team should transport sufficient supplies and equipment to effect any needed change in treatment on-site prior to flight and provide all care required during flight. This includes equipment needed for airway intubation and maintenance of ventilation, i.e. a tracheostomy set, a bag-valve resuscitation device, a transport ventilator, portable oxygen tanks, a pulse oximeter and an end-tidal CO_2 monitor. Additional equipment includes that necessary to perform a tube thoracostomy, an escharotomy and skin closure, as well as that needed to immobilize and splint extremities and administer fluids and other medications. The supplies that should accompany the flight team include intravenous fluids, wound dressings including large burn pads and reflecting blankets to minimize in-flight heat loss, topical antimicrobial agents, and the other medications commonly needed for the early care of severely burned patients. When transporting patients in aircraft with limited storage space, the equipment and supplies should be carried in small containers such as backpacks (15). Long-range aeromedical evacuation of intubated patients has been facilitated by the use of a pneumatic, time-cycled, pressure-limited transport ventilator (TXP® Military Transporter® Respirator, Percussionaire, Sandpoint, Idaho, USA) (46), and by a lightweight Kevlar®-aluminum composite oxygen cylinder (Structural Composite Industries, Pomona, CA, part number 1270152-3; empty weight 5.2–5.9 kg, volume 1000 litres, pressure 21257 KpA). The use of critical care monitors, infusion pumps, arterial blood gas analysers and suction devices enables one to establish an airborne Burn Intensive Care Unit for these patients. A current packing list for the US Army Burn Flight Team is provided in Table III.

The pre-flight stabilization measures most often required are placement of an intravenous cannula, placement of a nasogastric tube and insertion of a Foley catheter. The patient may also need endotracheal intubation, escharotomy, placement of a thoracostomy tube, alteration of fluid therapy to correct shock, oliguria and/or hypothermia, and the application of burn wound dressings (47). The risks of flight, and the measures employed to mitigate these, are summarized in Table IV.

International augmentation and aeromedical evacuation

Overseas fire disasters place an additional set of demands on the responding burn team. Such

Table III. Supply and equipment list, US Army Burn Flight Team.

Case 1
Portable ICU monitor (Propaq Encore, Welch Allen, Inc.)
I.v. infusion pumps (IVAC Medsystem III, Alaris Medical Systems, Inc.)
Special Medical Emergency Evacuation Device platform (SMEED, Impact Instrumentation, Inc.)

Case 2
Transport ventilator (battery-operated) (Impact Instrumentation, Inc.)
Portable suction unit (battery-operated) (Impact Instrumentation, Inc.)

Case 3
High-frequency percussive ventilator (VDR-4, Percussionaire, Inc.)
SMEED (modified for this ventilator)

Carry bag
Burn bedroll (1 cotton sheet, 1 orange pad, 5 burn pads, 1 aluminum blanket)
Gel pad (for head)
Heel protectors, foam

Hand-carried items
Digital camera
International cell phone
Laptop computer

Hand trucks (1–2)

Respiratory therapy rucksack
Transport ventilators, pneumatic (TXP, Percussionaire, Inc.)
Portable blood gas analyser (iSTAT, Inc.)
Fibreoptic bronchoscope (Olympus, Inc.)
Oxygen, air and TXP ventilator hoses
Albuterol solution
Albuterol metered dose inhaler (MDI)
Ipratropium MDI
Benzocaine spray
Lidocaine (1% solution; viscous)
Sodium chloride 0.9% bullets
Christmas tree adaptors
Scissors
Regulators
Nasal cannulae
Oxygen masks (simple, venturi, non-rebreather, aerosol)
Tracheostomy collar
Oxygen tubing, connectors
Laryngoscope kit
Oropharyngeal airways
Yankauer suction devices
Endotracheal tube changers
Ambu bags
Endotracheal tubes
Wright's respirometer
Endotracheal tube cuff manometer
Bacterial filters
Disposable end-tidal CO_2 detectors
Positive end expiratory pressure valves
Pulse oximetry probes
Endotracheal tube cuff repair kit
Batteries
Hand-held nebulizers
Umbilical tape
Nasal trumpets
Endotracheal tubes
Endotracheal tube stylets
Magill forceps
Suction catheters

Nursing rucksacks
<u>Kits</u>
Arterial line kit
Percutaneous introducer/central venous catheter kit
Wound care kits (burn pads, laparotomy pads, roller gauze, surgical stapler, staple remover)
I.v. insertion kits
Nasogastric intubation kit

Table III. (*Continued*).

Urethral catheterization kit
Emergency minor surgery tray
Tracheostomy tray
Tube thoracostomy tray
Eye kit
Light, eye, cobalt blue 3 V disposable
Fluorescein strips
0.9% sodium chloride bullets
Morgan lens
Eye moisture chamber
Bacitracin ointment, ophthalmic
Medications and special dressings
Silver sulfadiazine cream
Mafenide acetate cream
Mafenide acetate powder for aqueous solution
Dopamine
Potassium chloride
Sodium chloride 0.9% bags for injection (50 and 100 ml)
Silver-impregnated dressings (Silverlon, Argentum Medical, Inc.)
Bacitracin ointment
Antacids (magnesium- and aluminum-based)
Acetaminophen
Atropine sulfate
Calcium chloride
Dextrose, 50%
Adenosine
Epinephrine (adrenaline)
Norepinephrine (noradrenaline)
Sodium bicarbonate
Vecuronium
Midazolam
Diazepam
Mannitol
Morphine sulfate
Fentanyl
I.v. fluids
Lactated Ringer's solution
Albumin, 25%
5% dextrose in water
Secondary i.v. piggyback sets
Blood sets, gravity
4-way i.v. stopcocks
I.v. administration sets for infusion pump
I.v. connectors and adapters
Miscellaneous
Surgical gowns, masks, caps
Sterile and non-sterile surgical gloves
Scissors, bandages
Baby wipes
Soap, liquid
Sharps container
Needle holder and forceps
Trash bags
Oral maxillofacial wire cutters
Doppler flowmeter
Ultrasonic transducer gel
Stethoscope and sphygmomanometer
Applicators, disposable
Depressors, tongue
Lubricant, surgical
Povidone iodine applicators
Urinal
Adult limb restraints
Dobhoff feeding tubes
Collar, cervical, Aspen, adult
Cauterizer, hand-held, U-tip
Flashlight
Saw, finger ring

Table III. (*Continued*).

Razor, surgical prep
Scalpels, #10
Catheter, thoracic
Syringes, needles
Tape, surgical silk 1"
Pads, isopropyl-alcohol-impregnated

missions require the approval of the host nation government, as well as (in the case of the US Army burn team) approval on the part of the US government. While these approvals are being obtained, it is essential to determine the number and type of casualties that have been generated, the local medical resources that are available and the local environment in terms of climate, geography, immunization requirements, availability and characteristics of electric power, communication facilities, special cultural considerations and the need for and availability of interpreters. Careful attention must be paid to defining the purpose and limits of the mission, and to planning the response to the unrequested and unanticipated arrival of foreign physicians and others. If such 'volunteers' lack sufficient equipment and supplies to support semi-independent operation they may only place additional stress on a system that has been compromised by the disaster *per se*(15).

The composition, mission and activities of a burn augmentation team must be fashioned in accordance with the host nation's needs and environment. In a situation in which local facilities are sparse or destroyed, the team must be prepared to operate semi-independently and to provide triage, early care and transfer to a definitive care facility. On the other hand, when local facilities are intact but understaffed relative to the number of burn patients, the burn team may be required to provide longer-term definitive care, to include surgery and rehabilitation, and may be integrated into the local facility's staff. The latter mission was performed by US Army Burn Teams in Ufa, Russia in 1989 (see above).

The classification system of burn care facilities developed by the International Society for Burn Injuries (ISBI) provides a useful framework for assessment of host nation capabilities and for mission planning. Care at Level A facilities is limited to 24–48 hours, and consists of triage, initiation of resuscitation, preparation of patients for transfer and care of patients with minor injuries. Level B facilities provide resuscitation, wound care including grafting, and initial rehabilitation. Level C facilities are existing tertiary burn centres which provide definitive care including invasive monitoring, management of inhalation injury, early wound excision, complete rehabilitation, infection control and metabolic support.

In concert with this classification of burn care facilities, the ISBI Laboratory Committee has defined the level of support which should be provided at each level. Laboratory equipment and personnel are an essential component of a disaster response team and should not be omitted. At Level

Table IV. In-flight risks of aeromedical evacuation of burn patients.

Risk	Cause	Prevention
Dislodgement of endotracheal tube	Non-adherence of conventional tape to burned face; progressive oedema	Secure tube around patient's head with cotton umbilical tape
Hypoxia at altitude	Decrease in ambient partial pressure of oxygen at altitude	Ensure patient has adequate oxygenation pre-flight (PaO_2 to FiO_2 ratio of at least 160)
Worsening of burn shock	Under-resuscitation pre-flight or in-flight	Ensure patient is haemodynamically stable pre-flight. Continue fluid resuscitation in-flight
Loss of intravenous catheter	Non-adherence of conventional tape to burned extremities; progressive oedema	Place 2 large-bore i.v. catheters; suture in place
Hypothermia	Increased heat loss across burned skin	Warmed aircraft and fluids; reflective blankets; warming blankets; avoidance of wet dressings
Pressure ulceration	Prolonged immobilization on hard litters	Periodic repositioning; padded transport mattress
Vomiting and aspiration	Burn-shock-induced gastric ileus; expansion of gastric air bubble at altitude	Nasogastric intubation and decompression
Tension pneumothorax	Expansion of unrecognized pneumothorax at altitude	Review of chest radiograph prior to transport; physical examination; tube thoracostomy
Pneumocephalus	Expansion of intraocular or intracranial air	Avoidance of transport immediately following eye or brain surgery
Septic shock	Unrecognized pre-existing wound infection, pneumonia, etc.	Careful head-to-toe examination prior to transport; consideration of prophylactic antibiotics for long-range flight
Inappropriate patient selection; inadequate preparation of patient prior to transport team arrival	Inadequate physician-to-physician and nurse-to-nurse communication during planning phase	Early and ongoing communication between sending facility, receiving facility, and transport team representative

Table V. Selected major deployments of the US Army Burn Flight Team, 1977–2004.

Year	Incident	Number treated*	Burn Flight Team activities: A	B	C
1977	Crash of two airliners, Tenerife, Canary Islands	12	X		
1979	US Marine Corps barracks fire, Japan	38	X		
1980	Hostage rescue aircraft crash, Iran	4	X		
1980	Merchant vessel boiler explosion near Buenos Aires, Argentina	3	X		
1981	Plane crash on *USS Nimitz*, Pacific Ocean (Japan)	4	X		
1981	Honduran Air Force barracks fire, Honduras	11	X		
1983	Truck bombing of US Marine Corps Headquarters, Beirut, Lebanon	2	X		
1988	Airshow aircraft collision, Ramstein, Germany	7	X		
1989	Helicopter crash, Korea	13	X		
1989	Natural gas explosion involving two trains near Ufa, Russia	150		X	X
1990	Explosion on *USS Midway*, Pacific Ocean (Japan)	6	X		
1991	Operation Desert Shield/Storm, Saudi Arabia	65	X	X	
1994	Military aircraft collision and crash, Pope AFB, NC	43	X		
1997	US Air Force aircraft crash, Honduras	4	X		
1997	Civilian aircraft crash, Guam	16	X		
2000	Ammunition depot explosion, Guyana	10	X		X
2002	Fire in fireworks shopping zone, Lima, Peru	66			X
2003–present	Operation Iraqi Freedom	**	X	X	
2004	Fire in shopping mall, Asunción, Paraguay	64			X

A, Stabilization and aeromedical evacuation. B, Definitive care in a forward-deployed or host nation facility. C, Consultation and augmentation in a host nation facility. *Number seen or treated by members of the Burn Flight Team. **Ongoing.

A facilities, the ability to monitor serum chemistries and to perform complete blood counts is needed. At Level B facilities, definitive care support is required, to include expanded chemical analysis of blood and urine, blood gas measurements, blood transfusion therapy, microbiology, equipment sterilization, pharmacy and supply management. At Level C facilities, existing capabilities in the host nation burn centre are augmented to the extent necessary, and can include all components of Level B support as needed (15).

The US Army Burn Flight Team has performed a variety of missions in response to overseas fire disasters, ranging from consultation, to stabilization and aeromedical evacuation of patients to the USA, to definitive care in both host nation fixed facilities and military field hospitals. Major deployments of the Burn Flight Team in support of US and overseas disasters as well as combat operations are summarized in Table V.

Rehabilitation and long-term follow-up

Although the emphasis during the first hours and days following a burn mass casualty is on life-saving resuscitation and surgery, the occupational, physical and psychological rehabilitation of the survivors and their families is an essential component of the disaster response (11,48) and must be incorporated into relief operations from the onset. The effort required for this aspect of care is greatest for those patients with severe injury and typically intensifies after the resuscitation period. Early identification and treatment of acute stress disorder may reduce the incidence and severity of subsequent post-traumatic stress disorder.

After-action review

Finally, there is no substitute for self-critical after-action review soon after the event, and the publication of findings (18). The review may identify, for example, needed changes in the mass casualty disaster plan, staffing levels, or equipment and supply lists.

The US National Response Plan

Disaster response in the USA is multi-tiered, reflecting the federal structure of government and the limits placed on federal – in particular military – involvement in local activities. In contrast to smaller countries, the US federal government does not normally intervene in disasters. The levels of medical response available can be ranked as follows, from most likely to least likely to be employed:

- State and local response
- National Disaster Medical System
- Military Support to Civil Authorities.

Coordinating the large number of participating agencies and integrating the various levels of response is challenging. As a result, the US system was reorganized in the aftermath of the terrorist attacks of 11 September 2001 against the World Trade Center and the Pentagon, and continues to evolve. This reorganization included the creation of a new Department of Homeland Security (DHS). Homeland Security Presidential Directive (HSPD) 5, Management of Domestic Incidents, mandated that the US Government 'shall establish a single, comprehensive approach to domestic incident management … to ensure that all levels of government across the Nation have the capability to work efficiently and effectively together' (49). Under HSPD 5, the Secretary of DHS is the principal federal official responsible for domestic incident management. Initial responsibility lies with local and state officials; the federal government assists when state capabilities are overwhelmed, or when federal interests are involved. Implementation of HSPD 5 involves two core documents, the National Incident Management System (NIMS) (50) and the National Response Plan (NRP) (51). The NRP replaces the Federal Response Plan; the latter was activated, for example, on 11 September 2001 (52).

The National Disaster Medical System (NDMS), created in 1984, is responsible for managing and coordinating the federal medical response to major emergencies and federally declared disasters, including natural disasters, technological disasters, major transportation accidents and acts of terrorism including those involving weapons of mass destruction (WMDs). NDMS is now a section within the Federal Emergency Management Agency (FEMA) of the DHS, and works closely with the Department of Health and Human Services, the Department of Defense (DOD) and the Department of Veterans' Affairs (DVA).

NDMS may be activated in one of three ways: (i) the governor of an affected state may request a presidential declaration of disaster or emergency; (ii) a state health officer may request NDMS activation by the Department of Health and Human Services; or (3) the Assistant Secretary of Defense for Health Affairs may request NDMS activation when military patient levels exceed DOD and DVA capabilities, as during a major war (53). Just as Military Support to Civil Authorities, MSCA, is the final tier in the nation's domestic disaster response system, NDMS is the final tier in the military health care system for injured servicemen. The first tier for military casualties is the military hospital system, the second tier is the VA hospital system and the third tier is the NDMS system. Thus, the military backs up the civilian sector via MSCA, and the civilian sector backs up the military via NDMS.

NDMS has three functions: (i) medical response to the disaster site; (ii) patient movement from the disaster area to unaffected areas of the nation; and (iii) definitive medical care in unaffected areas (54). Following 11 September 2001, the first function was employed, but it was not necessary to evacuate patients to other, unaffected areas.

To provide a medical response to a disaster site, NDMS fosters the development of local Disaster Medical Assistance Teams (DMATs). Each DMAT is sponsored by a major medical centre or similar institution. They are composed of about 35 physicians, nurses, technicians and administrative support staff and are designed to provide medical care during a disaster or similar event. Burn Specialty Teams (BST) are specialized DMATs, composed of approximately 15 burn-experienced personnel, to include a surgeon (team leader), 6 registered nurses, 1 anaesthesia provider, 1 respiratory therapist, 1 administrative officer and 5 additional support personnel who are selected based on mission requirements. BSTs are primarily designed to augment existing local capabilities. There are currently four BSTs in the USA; these are based in Boston, Massachusetts; Gainesville, Florida; Galveston, Texas; and St Paul, Minnesota. Two more BSTs are planned. Each BST is affiliated with a local DMAT, to ensure the sharing of assets (S. Briggs, MD, personal communication, August 2004). DMATs and BSTs are mainly a community resource for local and state requirements, but they can be federalized to support national needs (54,55). DMATS from Maine, New Jersey, New York, Rhode Island and the BST from Massachusetts, were federalized and deployed to New York City in response to the events of 11 September 2001 (56).

Another form of support provided by NDMS at the disaster area is the Strategic National Stockpile programme (previously known as the National Pharmaceutical Stockpile), which was mobilized for the first time in response to 11 September 2001. This programme, when activated, provides needed supplies including intravenous (i.v.) fluids and medications, airway supplies, emergency medications and dressings (52). It is administered in collaboration with the Centers for Disease Control of the Department of Health and Human Services.

Under the provisions of NDMS, the patient regulation and movement mission is the responsibility of the DOD, and specifically of the Global Patient Movement Requirements Center (GPMRC) of the US Transportation Command, Scott Air Force Base, Illinois (57). Regulation is that portion of the air medical evacuation process by which patients are directed to the appropriate definitive-care hospital, such that patient needs are matched with hospital capabilities and bed space (55). US Air Force cargo aircraft are the primary assets used, but these can be augmented by civilian aircraft under the Civil Reserve Air Fleet (CRAF) programme (55).

Once casualties are evacuated out of a disaster area to an unaffected area, the local Federal Coordinating Center (FCC) takes over. The FCCs are operated by the Department of Defense (24 FCCs, operated by the Army, Navy and Air Force) and by the Department of Veterans' Affairs (37 FCCs) (53). FCCs are responsible for recruiting a voluntary network of non-federal hospitals to participate in NDMS. In addition, federal hospitals, to include VA and military hospitals, may receive patients under NDMS activation. Once NDMS is activated, GPMRC instructs the FCCs on bed reporting requirements. FCC coordinators then collect bed data from each participating NDMS hospital. These reports include two key elements: available beds and throughput. 'Available beds' means fully equipped, supplied and staffed beds. 'Throughput' means the number of patients who can be processed through a PRA and transported to local NDMS hospitals within a 24-hour period (55). Beds are categorized as follows: Critical Care, Paediatric, Medical/Surgical, Psychiatric, or Burn. This bed reporting capability is currently exercised bi-monthly (58). Under FCC supervision, patients are received at a Patient Reception Area (PRA) such as an airfield. They are retriaged and then transported by air or ground to a local or regional NDMS-participating hospital at which beds are available.

An unanswered question is how best to integrate the nation's burn care capability with NDMS. Wachtel et al. in 1989 reported on the relationship between burn centres in the USA and the NDMS (38). Not all burn centres are members of NDMS; in fact, some burn centres are not located in one of the NDMS metropolitan areas and therefore would not be receiving casualties under the NDMS system. Furthermore, some hospitals which report burn bed availability to the NDMS do not ordinarily care for burn patients. The principle that burn centres should be used for burn casualties was recognized in that article, and a classification scheme was proposed for NDMS hospitals receiving burn patients. Level 1 burn centres would be those verified by the American Burn Association, and Level 2 and Level 3 centres would be other hospitals that might occasionally take care of burn patients (38).

The issues raised by Wachtel et al. remain pertinent. The principle that burn centres should care for burn patients, and the fact that full-scale war could exceed the capacity of the US Army Burn Center in San Antonio, Texas, led medical planners to establish a national burn centre bed reporting system during the first Gulf War of 1990–1991 (59). A similar system was implemented at the beginning of the current conflict in Iraq in 2003. Seventy burn centres across the USA reported their daily burn bed availability via electronic mail to the USAISR. This information was collated and submitted to NDMS, to the US Air Force, to the American Burn Association (ABA, which provided liaison with civilian burn centres) and to a burn liaison officer at the US military hospital in Landstuhl, Germany. This would have permitted the regulation of burn casualties from Landstuhl to burn centres with open beds near aeromedical evacuation hubs within the USA, if a large number of burn casualties required burn centre care (39). The system was again briefly activated in August 2004 in response to a fire disaster in Paraguay. Recognizing the desirability of maintaining this capability on a permanent basis, quarterly testing of this system is currently under discussion.

In essence, then, parallel systems exist in the USA for distribution of burn patients: one sponsored by the NDMS, in which FCCs direct patient distribution to hospitals in unaffected areas; and one sponsored by the military and the ABA in collaboration with NDMS. Integration of these two systems is a likely future objective. Furthermore, the total number of open burn beds identified by the ABA/military programme was rarely over 500 on a given day, and the number of ICU beds was rarely over 200. Although this bed capacity may be sufficient for the majority of incidents involving conventional weapons or fires, the deployment of even a single 'small-yield' nuclear weapon would clearly overwhelm national burn capacity, and some attention should be paid to developing an approach to such a scenario.

In addition to NDMS, the US military is available to support a state's response to a disaster or other significant event under legislation known as the Robert T. Stafford Disaster Relief and Emergency Assistance Act of 1974 (the Stafford Act) (60). However, DOD will normally provide support only when other resources are not available, and only if such support does not interfere with DOD's primary mission (61). Military responses which would not involve the use of lethal force are termed Military Support to Civil Authorities (MSCA). The Secretary of the Army is the approving authority (DOD

Executive Agent) for MSCA, and the Army's Director of Military Support (DOMS) acts for the Secretary (62). In response to the attacks of 11 September 2001, FEMA, under the provisions of both the Federal Response Plan and the Stafford Act, made three requests for DOD medical support: to deploy the hospital ship *USNS Comfort* to New York City; to provide human remains pouches to New York City; and to set up a Disaster Mortuary Operational Response Team centre at an Air National Guard base near the city (61).

One important medical component of MSCA capabilities is the US Army Special Medical Augmentation Response Teams (SMARTs), created in 1998. The mission of the SMART teams in this type of scenario is to provide short-duration medical assistance to local, state, federal and DOD agencies responding to disasters, civil–military cooperative actions, humanitarian assistance missions, WMD incidents, or chemical, biological, radiological, nuclear, or explosive (CBRNE) incidents. There are a total of 37 Army SMART Teams, each of which consists of 2–12 personnel. These include teams specializing in emergency medicine; medical management of nuclear, biological, or chemical incidents; stress management; medical command and control, communications, and telemedicine; pastoral care; preventive medicine; burns; veterinary medicine; health systems assessment and assistance; and aeromedical isolation transportation. The latter team is responsible for movement of patients with highly contagious diseases such as Ebola haemorrhagic fever (63).

There are two Burn SMART Teams. These teams, staffed and operated by the US Army Burn Center at the US Army Institute of Surgical Research, Brooke Army Medical Center, Fort Sam Houston, TX, are identical to the Burn Flight Teams established in 1951 (see above). The areas of expertise recognized for the Burn SMART Teams include burn triage and resuscitation, management of inhalation injury and respiratory failure, trauma management, evacuation, and aeromedical transfer. The teams are capable of providing additional mechanical ventilation expertise regardless of aetiology of lung failure (mustard or nerve agent, etc.) (63). Direct involvement of DOD medical personnel in a domestic incident is considered a step beyond NDMS, and is intended to be limited in extent and duration. Thus, the Burn SMART Teams have not yet been utilized under MSCA, and continue to be used primarily for long-range aeromedical evacuation of combat burn casualties, and for assistance to foreign governments following burn mass casualty events (45,64).

Conclusions

Increasingly, the importance of rigorous, comprehensive preparation for mass casualty disasters is being recognized. A variety of excellent training resources are now available, including the Fundamentals of Disaster Management course, sponsored by the Society of Critical Care Medicine (28); Core, Basic, and Advanced Disaster Life Support courses, sponsored by the American Medical Association; and the Advanced Disaster Medical Response Provider Course, sponsored by the International Trauma and Disaster Institute of the Massachusetts General Hospital (35). The Advanced Trauma Life Support course of the American College of Surgeons (65) includes a section on disaster planning. A new module is also being developed for the Advanced Burn Life Support Course, which will include management of burn mass casualty disasters (66).

Additionally, in order to respond adequately to a burn mass casualty disaster, a community must both possess a viable disaster plan, and must have exercised that plan under strenuous and realistic conditions. As in the military, there is no substitute for rigorous, pertinent training. Such training must be a priority for the hospital and the community. Commitment on the part of all involved organizations and personnel is the key to effective preparation for burn mass casualty incidents.

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